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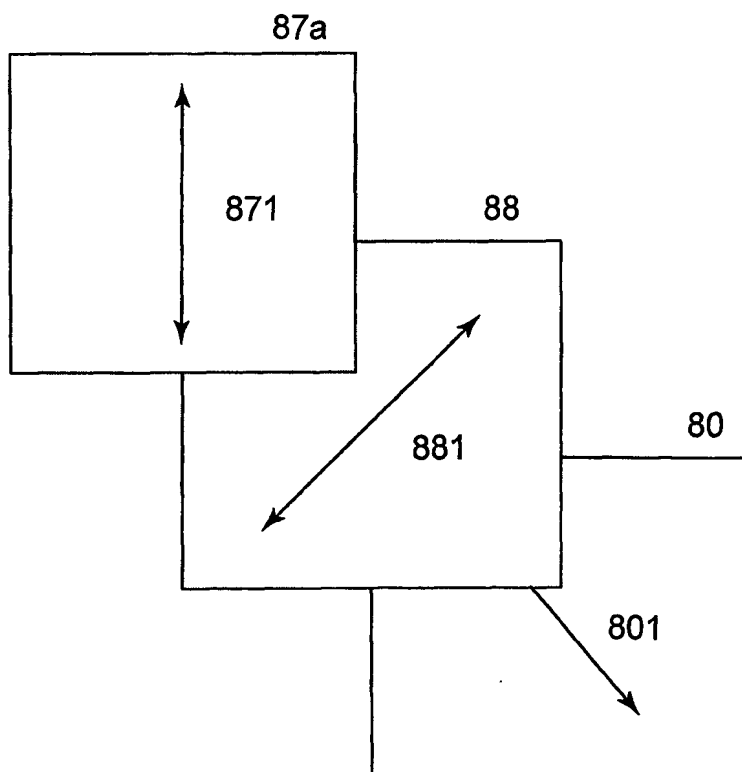
(57) Abstract: A liquid crystal display apparatus includes at least one polarization plate, a phase difference plate, a pair of oppositely disposed substrates at least one of which is a transparent substrate, a liquid crystal disposed between said pair of substrates, and means for applying a voltage to said liquid crystal so that a retardation of said liquid crystal is modulated depending on the voltage applied to said liquid crystal. The liquid crystal is placed in a first alignment state which is determined by said pair of substrates when the voltage is not applied thereto. The phase difference plate has a retardation so that light passing through said liquid crystal, said phase difference plate, and said polarization plate assumes chromatic color when the voltage is not applied to said liquid crystal. The liquid crystal is placed in a second alignment state in which said liquid crystal is aligned obliquely compared with the first alignment state so that the retardation of said liquid crystal cancels the retardation of said phase difference plate when the voltage is applied to said liquid crystal.

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DESCRIPTION

COLOR LIQUID CRYSTAL DISPLAY DEVICE

5   [TECHNICAL FIELD]

The present invention relates to a liquid
crystal display apparatus, particularly an
electrically controlled birefringence (ECB)-type
liquid crystal display apparatus.

10

[BACKGROUND ART]

At present, liquid crystal displays as an
example of liquid crystal display apparatuses have
widely been popularized as various monitors for a
15   personal computer and the like and as a display device
for a cellular phone, and so on. In the future, the
liquid crystal displays are expected to follow
popularization more and more, such as development in
use for big-screen television.

20   As a color display method for the liquid
crystal displays, one called a micro-color filter
method has been used widely.

The micro-color filter method effects
full-color display by dividing one pixel into at least
25   three sub-pixels and providing the three sub-pixels
with color filters of three primary colors of red (R),
green (G), and blue (B), respectively, thus having an

advantage of readily realizing a high
color-reproducing performance.

However, as a disadvantage of the micro-color
filter method, a transmittance is 1/3 of a
5   monochromatic display method, so that a light
utilization efficiency is low.

This low light utilization efficiency leads to
a high power consumption since it is necessary to
increase a luminance of a back light or a front light
10   when bright display is intended to be effected in a
transmission-type liquid crystal display apparatus
having the back light, a transflective
(semi-transmission)-type liquid crystal display
apparatus having the back light, or a reflection-type
15   liquid crystal display apparatus having the front
light.

The low light utilization efficiency is a more
serious problem in the case of a reflection-type
liquid crystal display device without using the back
20   light. More specifically, a reflection-type color
liquid crystal display device provided with the RGB
color filters can ensure a sufficient viewability in
extremely bright outdoors. On the other hand, however,
it is difficult to ensure the sufficient viewability
25   not only in a dark place but also in an environment of
brightness in office or home.

On the other hand, as a color liquid crystal

display apparatus for effecting color display without
using the color filter, an ECB-type liquid crystal
display apparatus, as proposed by U.S. Patent No.
6,014,195, has been known. The ECB-type liquid crystal
5 display apparatus is generally constituted by a pair
of substrates and liquid crystal sandwiched between
the substrates, and is roughly classified into those
of a transmission-type and a reflection-type.

In the case of the ECB-type liquid crystal
10 display apparatus of the transmission-type, each of
the pair of substrates is provided with a polarization
plate. On the other hand, in the case of the ECB-type
liquid crystal display apparatus of the
reflection-type, there are one-polarization plate type
15 display apparatus in which only one of the substrates
is provided with a polarization plate and
two-polarization plate type display apparatus in which
both of the substrates are provided with a
polarization plate and a reflection plate is disposed
20 outside each of the polarization plate.

In the case of the ECB-type liquid crystal
display apparatus of the transmission-type, linearly
polarized light which comes in through one of the
polarization plates is changed into elliptically
25 polarized light consisting of respective wavelength
light fluxes different in state of polarization by the
action of birefringence of liquid crystal layer in a

process of transmitting a liquid crystal cell. The elliptically polarized light enters the other polarization plate and the transmitted light having passed through the other polarization plate is colored

5   light consisting of light fluxes of colors corresponding to light intensities of the respective wavelength light fluxes.

In other words, the ECB-type liquid crystal display apparatus is capable of coloring light by

10 utilizing the birefringence action of the liquid crystal layer of the liquid crystal cell and the polarization action of at least one polarization plate without using the color filter.

As described above, the ECB-type liquid

15 crystal display device causes no light absorption by the color filter, so that it is possible to effect bright color display at a high transmittance of light.

In addition, in the ECB-type liquid crystal display apparatus, the birefringence of the liquid

20 crystal layer is changed by an alignment state of liquid crystal molecules depending on a voltage applied between electrodes of both of the substrates of the liquid crystal cell. In correspondence thereto, the state of polarization of the respective wavelength

25 light fluxes entering the other polarization plate is changed. For this reason, by controlling the voltage applied to the liquid crystal cell, it is possible to

change the color of the colored light. As a result, it
is possible to display a plurality of colors at one
(the same) pixel.

In the case where the ECB-type liquid crystal
5   display apparatus of the transmission-type is driven
in a crossed-Nicol condition, it is found that the
color is changed depending on an amount of retardation,
i.e., birefringence. In the case where, e.g., the
liquid crystal device uses a liquid crystal material
10 having a negative dielectric anisotropy (- $\Delta \varepsilon$) such
that liquid crystal molecules are homeotropically
(vertically) aligned to assume black under no voltage
application. With an increase in voltage, the color is
changed in the order of
15 black-gray-white-yellow-red-violet-blue-yellow-violet-
light blue-green.

However, in such a conventional liquid crystal
display apparatus which effects display in the above
described ECB mode, it is possible to effect arbitrary
20 color display at the same pixel. However, the ECB mode
is a mode utilizing coloring by retardation, so that
there has arisen such a problem that a display color
is changed by a change in retardation with temperature.

Further, when there is an irregularity in
25 temperature in a panel plane, the temperature
irregularity is visually identified as an irregularity
in display color. It is possible to obviate the

temperature irregularity by performing temperature

compensation in principle. However, when fine

temperature compensation is performed, it leads to an

increase in total production cost of the entire

5   display apparatus.   .   ·

In the ECB mode, a viewing angle

characteristic is also limited. Further, in the ECB

mode, it is difficult to effect full-color display

although multi-color display can be effected.

10   Further, in the ECB mode, it is clear from its

color display principle that the display color is

largely changed by a change in cell thickness.

Accordingly, in such a process that a uniform cell gap

is provided by using a pair of (upper and lower)

15   substrates in combination, the ECB requires change for

more strictly than other display modes. As a result,

it is considered that this requirement is a large

impediment to improvement in production yield.

20   [SUMMARY OF THE INVENTION]

An object of the present invention is to

provide a liquid crystal display apparatus having a

solved the above described problems.

A specific object of the present invention is

25   to provide a liquid crystal display apparatus capable

of effecting color display by utilizing a coloring

phenomenon on the basis of an ECB effect without

causing substantially no temperature dependence of hue
of display color.

According to an aspect of the present
invention, there is provided a liquid crystal display
5   apparatus, comprising:

at least one polarization plate,

a phase difference plate,

a pair of oppositely disposed substrates at
least one of which is a transparent substrate,

10   a liquid crystal disposed between the pair of
substrates, and

means for applying a voltage to the liquid
crystal so that a retardation of the liquid crystal is
modulated depending on the voltage applied to the

15   liquid crystal,

wherein the liquid crystal is placed in a
first alignment state which is determined by the pair
of substrates when the voltage is not applied thereto,

wherein the phase difference plate has a

20   retardation so that light passing through the liquid
crystal, the phase difference plate, and the
polarization plate assumes chromatic color when the
voltage is not applied to the liquid crystal, and

wherein the liquid crystal is placed in a

25   second alignment state in which the liquid crystal is
aligned obliquely compared with the first alignment
state so that the retardation of the liquid crystal

cancels the retardation of the phase difference plate
when the voltage is applied to the liquid crystal.

In a preferred embodiment of the liquid
crystal display apparatus, when a voltage having a
5   value which is not more than a predetermined value is
applied to said liquid crystal, the retardation of the
liquid crystal is modulated in a hue change range in
which the light passing through the liquid crystal,
the phase difference plate, and the polarization plate
10   assumes chromatic color and a hue of the chromatic
color is changed depending on the applied voltage and,
when a voltage having a value which is not less than
the predetermined value is applied to the liquid
crystal, the retardation of the liquid crystal is
15   modulated in a light brightness change range in which
a brightness of the light passing through the liquid
crystal, the phase difference plate, and the
polarization plate is changed depending on the applied
voltage, whereby achromatic color is displayed.

20   As another embodiment, the liquid crystal
display apparatus of the present invention may be
provided with a color filter through which the above
described chromatic or achromatic color is displayed.
More specifically, when the color of the color filter
25   is green and the retardation of the liquid crystal has
a value for displaying red or blue in the hue change
range, green of spectrum colors of the light passing

through the liquid crystal layer is absorbed by the
color filter. As a result, the resultant color is
color which is almost near the black.

In an important embodiment of the liquid
5   crystal display apparatus of the present invention,
when a color image is displayed at a plurality of
pixels, one color is displayed by a combination of a
first pixel at which the retardation of the liquid
crystal is modulated over the hue change range wherein
10 the hue of the chromatic color is changed depending on
the applied voltage having the value which is not more
than the predetermined value and the brightness change
range wherein the brightness is changed depending on
the applied voltage having the value which is not less
15 than the predetermined value, and a second pixel at
which a color filter is provided and the retardation
of the liquid crystal is modulated in the hue change
range wherein the brightness is changed depending on
the applied voltage having the value which is not less
20 than the predetermined value.

More specifically, the unit pixel is
constituted by a plurality of sub-pixels including a
first sub-pixel at which the retardation of the liquid
crystal is modulated over the hue change range wherein
25 the light passing through the liquid crystal, the
phase difference plate, and the polarization plate
assumes the chromatic color and the hue of the

chromatic color is changed and a brightness change

range wherein the light assumes achromatic color and a

brightness of the achromatic color is changed, and a

second sub-pixel at which a color filter is provided

5   and the retardation of the liquid crystal is changed

in the brightness change range wherein the brightness

of the light passing through the liquid crystal, the

phase difference plate, and the polarization plate is

changed.

10   By appropriately selecting a retardation of

the phase difference plate, the display color in no

voltage application state is blue or bluish green. In

this case, by providing a green color filter at the

second sub-pixel, it is possible to effect three

15   primary colors. Further, by providing a color filter

of color complementary to green at the first sub-pixel,

it is possible to enhance a purity of the display

color.

           In a preferred embodiment, by appropriately

20   selecting the retardation of the phase difference

plate, the display color in no voltage application

state is green. In this case, by providing a red color

filter at the second sub-pixel, a color

reproducibility of red is good. Further, by providing

25   a color filter of color complementary to red at a

pixel (sub-pixel) capable of changing interference

color by a birefringence effect, it is possible to

enlarge a color space of the display color.

Incidentally, the liquid crystal display apparatus of the present invention may be used as a reflection-type liquid crystal display apparatus, a transflective-type liquid crystal display apparatus, or a transmission-type liquid crystal display apparatus.

These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the accompanying drawings.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Figure 1 is a schematic sectional view showing a structure of an embodiment of the liquid crystal display apparatus according to the present invention.

Figures 2(a), 2(b), 3 and 4 are schematic views each showing a pixel constitution used in Example of the present invention.

Figure 5 is a graph showing a relationship between an applied voltage and an effective refractive index anisotropy of an ECB liquid crystal display apparatus at different temperatures.

Figure 6 is a chromaticity diagram showing a relationship between a retardation and display color

in a conventional ECB liquid crystal display device.

Figure 7 is a schematic view for illustrating a change in alignment state of liquid crystal molecules in the liquid crystal display apparatus of the present invention.

Figure 8 is a schematic view for illustrating a constitution of the liquid crystal display apparatus of the present invention.

[BEST MODE FOR CARRYING OUT THE INVENTION]

Hereinbelow, embodiments of the present invention will be described with reference to the drawings.

Figure 1 is a schematic sectional view showing a structure of a liquid crystal display apparatus as an embodiment of the present invention.

Referring to Figure 1, a liquid crystal display apparatus 70 includes a pair of polarization plates 87a and 87b having polarization axes which intersect each other at right angles, and a liquid crystal device 80 sandwiched between the pair of polarization plates 87a and 87b. The liquid crystal device 80 principally includes a pair of substrates 81a and 81b formed of a high transparent material, such as glass or plastics, and nematic liquid crystal (hereinafter, simply referred to as "liquid crystal") 85 disposed between the pair of substrates 81a and 81b.

13

The substrates 81a and 81b are provided with
electrodes 82a and 82b, respectively, for applying a
voltage to the liquid crystal (layer) 85. These
electrodes 82a and 82b are stripe-like electrodes
5   which intersect each other, thus forming a matrix
electrode structure.

In the case where the reflection-type liquid
crystal display apparatus is prepared, the electrode
82b may preferably be a metal electrode of aluminum,
10   silver, or the like, having a reflection property. The
metal electrode may preferably have an uneven surface
shape, as a surface shape, suitable for realizing a
light diffusion characteristic. In the case of the
reflection-type liquid crystal display apparatus using
15   the metal electrode, the polarization plate 87b may be
omitted. Further, in the case of providing the
transflective-type liquid crystal display apparatus,
the apparatus is realized by forming two areas
including an area constituted by the reflective metal
20   electrode and an area constituted by the ITO electrode.

Incidentally, as the electrode structure, it
is also possible to form an active matrix structure by
disposing dot-like transparent electrodes each
connected with TFT or MIM (metal-insulator-metal) as a
25   switching element on one of the substrates in a matrix
form and disposing an opposite electrode on the entire
surface of the other substrate or in a predetermined

pattern.

On these electrodes 82a and 83a, insulating films 83a and 83b having a short-circuit prevention function are formed, respectively, as desired. Further,

5   on the insulating films 83a and 83b, alignment control films 84a and 84b are formed, respectively, so as to contact a liquid crystal 85 and function as a film for controlling an alignment state of the liquid crystal 85.

10   A phase difference plate 88 has a predetermined retardation. On or under the phase difference plate 88, it is also possible to use a film having a light scattering function (not shown).

Incidentally, the liquid crystal display

15 apparatus 70 using an ordinary ECB effect-based coloring phenomenon can control the hue of display color by utilizing a change in retardation due to the change in applied voltage, and the color liquid crystal display apparatus using such a retardation

20 change has been known.

Here, as a color displayable mode on the basis of the above described ECB principle, various alignment modes, such as a homeotropic (vertical) alignment mode, a homogeneous (parallel) alignment

25 mode, a hybrid aligned nematic (HAN) mode, an optically compensated bend (OCB) mode, a super twisted nematic (STN) mode, and so on, may be considered. All

the modes are such an alignment mode in which an amount of birefringence (hereinafter referred to as a "retardation") of the liquid crystal layer is changed by voltage application.

As described above, when the retardation is changed, a spectrum of light passing through the liquid crystal layer is changed in the case where white light is incident in the liquid crystal layer, so that hue of the transmitted light is changed along the curve shown in Figure 6.

When the homeotropic alignment mode is taken into consideration, the liquid crystal molecules are aligned perpendicular to the substrate under no voltage application, so that a retardation is substantially zero. With an increase in voltage applied to the liquid crystal layer, the liquid crystal molecules are inclined to increase the retardation. As a result, on the chromaticity diagram, the color of the transmitted light is changed in the order of black, gray, white, yellow, red, violet, blue, yellow, light blue, and green. In other liquid crystal alignment modes, the retardation at the applied voltage of zero and the manner of change thereof with respect to the applied voltage are changed variously but the change in color with respect to the retardation is similar to that in the homeotropic alignment mode.

As a result of study of the inventor on an optimum alignment mode with respect to these alignment modes, it has been clarified that the homeotropic alignment mode is optimum in order to minimize the

5 change in display color by the change in temperature and enlarge a cell thickness margin. Hereinbelow, details thereof will be described.

In the case of the nematic liquid crystal, various physical properties thereof are changed with

10 respect to temperature. Particularly, it has been known that the nematic liquid crystal has a large temperature dependence of a refractive index anisotropy (Δn) as a physical property parameter which effects a display characteristic. Such a change

15 in characteristic attributable to the temperature dependence of the physical property manifects itself considerably as the change in display color by the coloring phenomenon on the basis of the above described ECB effect.

20 When a temperature dependence of a retardation value of a commercially available Nn-type liquid crystal material is measured, there are also some materials for which the temperature dependence of the retardation some materials for which the temperature

25 dependence of the retardation value is not substantially observed in an intermediary voltage range between a threshold value of Freederiksz

transition and a saturation voltage value. This may be attributable to realization of such a voltage range in which although the temperature dependence of Δn is present, the temperature dependence of elastic

5   constant affects the alignment of liquid crystal under voltage application and cancels the temperature dependence of Δn, so that the resultant temperature dependence of retardation is very small or is not substantially present.

10   However, even with respect to the above described liquid crystal materials, it has been confirmed experimentally that the retardation value has a large temperature dependence when a voltage close to the saturation voltage value is applied.

15 Figure 5 shows measurement results of retardation values. More specifically, an abscissa represents an applied voltage and an ordinate represents an effective refractive index anisotropy (Δn_{eff}) obtained by dividing retardation by cell thickness.

20 The measurement is performed at temperatures from 0 °C to 40 °C.

From the results of Figure 5, it is found that the retardation in changed with temperature at high voltages applied to the liquid crystal material. This

25   is presumably because almost all liquid crystal molecules of the liquid crystal layer including those in a bulk state and those located at the interfaces

with the substrates are homogeneously aligned in
parallel with the substrates by applying thereto a
sufficiently high voltage, so that they are affected
by the temperature dependence of Δn as they are to

5   result in a very large temperature dependence of
retardation.

However, up to an intermediary voltage, the
temperature dependence of retardation is substantially
zero or very small but at high voltages, the

10   temperature dependence of retardation is noticeable.
For this reason, with respect to the color display on
the basis of ECB principle in the present invention,
the color display is effected in such a voltage range
that the temperature dependence of retardation is

15   substantially zero or very small and in another
voltage range, the change in retardation with
temperature is large. Accordingly, another voltage
range is used as such a brightness change range that
the change in color is less obvious. As a result, it

20   is possible to realize such a liquid crystal display
apparatus 70 (liquid crystal device 80) that the
temperature dependence during color display is not
visually identified as the change in color.

In this embodiment, the liquid crystal layer

25   in which the liquid crystal molecules are placed in
such a state that they are substantially
homeotropically aligned in a direction perpendicular

to the substrates when no voltage is applied to the liquid crystal layer is used. In the homeotropic alignment state, however, the substrate surface is actually subjected to such a treatment that the liquid

5   crystal molecules are obliquely aligned in the neighborhood of the substrate surface at an inclination angle of ten and several degrees from a normal to the substrate surface so as to realize an oblique alignment (state) described later.

10   Incidentally, the homeotropic or vertical alignment (state) includes not only such an alignment (state) that a director of liquid crystal located close to the substrate surface or at a bulk portion is aligned strictly perpendicular to the substrate but also such

15   an alignment (state) that the liquid crystal molecules are inclined at the substrate surface but the influence of the inclination is not exerted on the bulk state liquid crystal and such an alignment (state) that the influence of the inclination is

20   exerted on the bulk state liquid crystal to incline the liquid crystal molecules at an inclination angle of several degrees to ten and several degrees. When the liquid crystal molecules at the bulk portion are inclined, the retardation is not zero but as described

25   hereinbelow, in the present invention, a total retardation of the liquid crystal layer and the phase difference plate under no voltage application may be

set so as to provide chromatic color, so that the
liquid crystal molecules in the liquid crystal layer
may be placed in any initial alignment state so long
as the total retardation is set as described above.

5   By the inclination alignment treatment
(pretilt treatment) in the neighborhood of the
substrate surface, an axis of easy inclination of the
bulk liquid crystal is aligned, so that the
retardation of the liquid crystal layer at the time of

10   no voltage application is zero. In order to effect
color display at the time of no voltage application, a
phase difference plate having a predetermined
retardation is disposed so as to permit display of
chromatic color under no voltage application. For

15   example, the retardation of the phase difference plate
is set to 300 nm and when the phase difference plate
is used in a reflection-type liquid crystal display
apparatus, a reciprocating phase difference of 600 nm
is obtained, thus permitting display of blue.

20   When a liquid crystal material having a
negative dielectric anisotropy is used, the liquid
crystal molecules are placed in an oblique alignment
state in which they are inclined with respect to the
substrate when a voltage is applied thereto. As

25   described above, by providing the alignment film with
such an axiality that the easy inclination axis is
directed in a desired direction when the alignment

treatment of the substrate is performed, the liquid

crystal molecules are inclined in the direction. In

the case where the bulk liquid crystal molecules have

already been inclined when the voltage is not applied

5   thereto, the inclination becomes large in the

direction by the voltage application.

The states of liquid crystal molecules which

are gradually inclined when the voltage applied to the

liquid crystal layer is increased is shown in Figure 7.

10   As shown in Figure 7, when an AC voltage

having a larger effective value toward the rightmost

view is applied from a power source 90 to electrodes

82a and 82b of substrates 81a and 81b, a liquid

crystal director (a unit vector representing a

15   direction of liquid crystal molecular long axis) 851

is gradually inclined as shown in from the leftmost

view to the rightmost view. The inclination plane is a

plane having the easy inclination axis.

With respect to the inclination direction of

20   the liquid crystal molecules 851 determined by the

easy inclination axis provided to the alignment film

(84a in Figure 1 and not shown in Figure 7), the phase

difference plate (88 in Figure 1 and not shown in

Figure 7) is disposed to have a slow axis

25   perpendicular to the inclination direction.

Figure 8 is a view showing an angular

relationship between an easy inclination axis 801 of a

liquid crystal layer 80, a slow axis 881 of a phase

difference plate 88, and a polarization axis 871 of a

polarization plate 87a when a reflection-type liquid

crystal display apparatus is viewed from a direction

5   perpendicular to the substrate surface. In this case,

the polarization plate 87a is used singly.

As shown in Figure 8, with respect to the

direction 871 of the inclination of liquid crystal

molecules, the slow axis 881 of the phase difference

10   plate is disposed perpendicularly and on the other

hand, the polarization plate 87a is disposed so that

the polarization plane 871 of incident light forms an

angle of 45 degrees. The arrangement shown in Figure 8

is that in the case where the liquid crystal material

15   used has a positive refractive index anisotropy. The

liquid crystal material having the positive refractive

index anisotropy has a larger refractive index, in a

molecular axis direction, than a refractive index in a

direction perpendicular to the molecular axis

20   direction, so that the easy inclination axis 801 is

the slow axis with respect to the retardation of the

liquid crystal layer 80.

In this case, by applying a voltage to the

liquid crystal layer, the retardation of the liquid

25   crystal layer cancels the retardation of the phase

difference plate to reduce a total retardation of the

liquid crystal layer and the phase difference plate.

Assuming that the total retardation is 700 nm
and display of blue is effected under no voltage
application, the retardation of the liquid crystal
layer is increased with the voltage and the total

5   retardation is decreased. As a result, the color of
light passing through the liquid crystal layer, the
phase difference plate, and the polarization plate in
a reciprocating manner in changed from blue to red
through magenta. When the total retardation is

10   decreased to not more than 250 nm by further
increasing the applied voltage, the color is removed
to result in a change in brightness. In this range, it
is possible to effect monochromatic display and
continuously control a monochromatic gradation level

15   by the applied voltage.

By adopting the above described device
constitution, it becomes possible to realize the
liquid crystal display apparatus 70 (liquid crystal
device 80) which is a color displayable device no the

20   basis of the ECB effect and has no temperature
dependence of a color display characteristic.

In the present invention, the liquid crystal
material is required to increase the inclination angle
from the normal to the substrate with respect to the

25   increase in voltage applied thereto. In the above
described embodiments, an electric field is applied
perpendicularly to the substrate by using the liquid

crystal material having the negative dielectric

anisotropy. However, the present invention is not

necessarily limited to such a case. Even when the

electric field is applied in a direction which is

5   parallel with the substrate and along the easy

inclination axis by using a liquid crystal material

having a positive dielectric anisotropy, a degree of

inclination of liquid crystal molecules is also

increased with voltage similarly as in the above

10   described case. Accordingly, the present invention is

also applicable to such a case.

Next, a cell thickness dependence will be

described.

Generally, the retardation of the liquid

15   crystal device is represented by the following

formula:

Δn_{eff} (V) x d,

wherein Δn_{eff} (V) represents a value of average

refractive index in such a state that a voltage is

20   applied to the liquid crystal layer (herein referred

to as an "effective refractive index value"), and d

represents a thickness of the liquid crystal layer.

Assuming that the liquid crystal device has a

variation in cell thickness and an amount thereof from

25   a center value d of the cell thickness is Δd, the

retardation of the liquid crystal device can be said

that it is within a range represented by the following

formula:

$$\Delta n_{eff} \ (V) \ x \ (d \pm \Delta d).$$

When respect to ordinary nematic liquid crystal materials, it is clear that Δn_{eff} (V) has no cell thickness dependency, so that a degree of variation of retardation when the cell thickness varies is represented by the following formula:

$$\Delta n_{eff} \ (V) \ x \ \Delta d.$$

In the conventional ECB-type color liquid crystal display apparatus, the liquid crystal layer has a large retardation value even at the time of color display. On the other hand, in the liquid crystal display device of the present invention, the effective refractive index value (Δn_{eff} (V)) of the liquid crystal layer at the time of color display is a considerably small value. In other words, even when the cell thickness varies, the resultant retardation of the liquid crystal layer (i.e., Δn_{eff} (V) x Δd has a small value, so that the change in hue during color display is remarkably suppressed compared with the case of the conventional liquid crystal display device.

Based on the above described effect, in the present invention, it becomes possible to provide a display device having a large cell thickness process margin.

Further, the liquid crystal device 80 in the present invention can be used as a color liquid

crystal display device capable of displaying all the
color ranges of RGB by combining a sub-pixel for
displaying blue in no voltage application state
through the ECB effect-based coloring phenomenon and a
5   sub-pixel provided with a green color filter as a
sub-pixel constituting each of a large number of
pixels, i.e., by using the green color filter at a
part of the sub-pixels constituting the pixels, as
desired.

10   In this case, by using a color filter of a
color, such as magenta, complementary to the color of
the green color filter at the pixel capable of
utilizing the ECB effect-based coloring phenomenon, it
becomes possible to enlarge a displayable color space.
15   Further, at other pixels, red and blue color filters
are used to permit full-color display.

Alternatively, the liquid crystal device 80 in
the present invention can be used as a color liquid
crystal display device capable of displaying all the
20   color ranges of RGB and having a high color
reproducibility of red by combining a sub-pixel for
displaying green in no voltage application state
through the ECB effect-based coloring phenomenon and a
sub-pixel provided with a red color filter as a
25   sub-pixel constituting each of a large number of
pixels, i.e., by using the red color filter at a part
of the sub-pixels constituting the pixels.

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In this case, by using a color filter of a color, such as cyan, complementary to the color of the red color filter at the pixel capable of utilizing the ECB effect-based coloring phenomenon, it becomes

5   possible to enlarge a displayable color space. Further, at other pixels, green and blue color filters are used to permit full-color display.

Incidentally, the liquid crystal display apparatus of the present invention can be driven by

10   any of a direct drive method, a simple matrix drive method, and an active matrix (AM) drive method. Further, the liquid crystal display apparatus may be of the transmission-type, the reflection-type, or the transflective-type. The substrate used may be glass or

15   a flexible material such as plastics. In the case of the reflection-type liquid crystal display apparatus, as a reflection plate, it is possible to use those of various types such as a so-called front scattering type in which a mirror reflection plate is used as the

20   reflection plate and a scattering plate is outside a liquid crystal layer, and a direction diffusion reflection plate having a directive reflection surface by appropriately designing the shape of the reflection surface.

25   As the liquid crystal material, the nematic liquid crystal material having a negative dielectric anisotropy is used, and on the basis of the presence

28

of such a voltage range that a change rate of a retardation R to a temperature ($\Delta R / \Delta T$) is substantially zero under such an applied voltage condition that the applied voltage is not less than a

5   threshold value of Freedericksz transition, the coloring phenomenon utilizing the ECB effect in this voltage range is used. As a result, a bright display device which has minimized the change in display color with the change in temperature is obtained, so that

10   the display device has a large cell thickness process margin to expect an improvement in yield. Further, it is possible to provide a change having a wide viewing angle.

Hereinbelow, the present invention will be

15   described based on Examples.

In the following examples, a common device structure described below is used.

As a structure of a liquid crystal layer, two glass substrates subjected to homeotropic (vertical)

20   alignment treatment are applied to each other with a gap therebetween to prepare a cell. In the gap of the cell, a liquid crystal material ("MLC-6608", mfd. by Merk & Co., Inc.) having a negative dielectric anisotropy ($\Delta \varepsilon < 0$) is injected by a capillary

25   action. At this time, a cell thickness is changed, depending on the examples, so as to appropriately set a retardation value.

As a substrate structure used, (1) a single bit test cell for measuring the retardation value, and (2) an active matrix (AM) cell for evaluating a display characteristic are used.

5   The single bit test cell is prepared by applying two substrates each provided with a patterned electrode of ITO (indium-tin-oxide) having a 1 cm-square area. The AM cell include an AM substrate provided with TFTs (thin film transistors) and an
10 ITO-formed substrate which is provided with or not provided with a color filter depending on the examples. Further, depending on the examples, a pixel shape and a color filter constitution are changed.

As a pixel electrode on the TFT-provided AM
15 substrate, or aluminum electrode is used to provide a reflection-type constitution, and a front scattering plate (mfd. by Polatechno Co., Ltd.) is disposed at an outermost surface of the AM substrate to enlarge a viewing angle. Further, in each of the single bit test
20 cell and the AM cell, an alignment film ("JALS 2021", mfd. by JSR Corp.) is formed in a thickness of 50 nm, and the substrate provided therewith is subjected to rubbing to provide a pretilt angle of about 1 degree from a direction of a normal to the substrate.

25 (Measurement of retardation)

By using the single bit test cell, a temperature dependence of retardation is measured.

More specifically, a polarizing microscope is used for
measuring the retardation under a cross-nicol
condition in combination with a Bereck-type
compensator (mfd. by Olympus Optical Co., Ltd.).

5   Measurement of the retardation is performed with
respect to four types of cells having different cell
thicknesses of (a) 4.0 μm, (b) 5.0 μm, (c) 6.0 μm
and (d) 7.0 μm.

As a result, with respect to all the cells, it

10   is confirmed that the temperature dependence is not
observed in a voltage range of not more than 3.2 V. On
the other hand, through observation of optical
response, with respect to all the cells, a threshold
voltage of Freedericksz transition is about 2.1 V.

15   In other words, by the above measurement, it
is confirmed that there is a voltage range in which a
change rate (ΔR/ ΔT) of retardation R to temperature
T of the liquid crystal material (MLC-6608) having Δ
ε < 0 is substantially zero under a condition of an

20   applied voltage of not less than the threshold voltage
of Freedericksz transition and that a maximum voltage
value in the voltage range is about 3.2 V.

(Comparative Example 1)

An AM cell, having a diagonal size (length) of

25   12 inches and SVGA (800x600x3) pixels, for evaluating
a display characteristic is prepared. The AM is not
provided with a color filter and includes a wide-band

λ/4 plate (phase-compensation plate capable of

substantially satisfying 1/4 wavelength condition in

visible light region) disposed between the upper

substrate (not provided with the TFTs) and the

5   polarization plate, thus providing such a normally

black constitution that a dark state is given at the

time of no voltage application and a bright state is

given at the time of voltage application. In this case,

four types of cells having different cell thicknesses

10 of (a) 4.0 μm, (b) 5.0 μm, (c) 6.0 μm, and (d) 5.0

μm are used.

        By using these cells, a temperature dependence

of chromaticity is measured by a measuring apparatus

("BM 7", mfd. by TOPCON Corp.) under conditions

15 including a drive voltage of up to 5 V under a

constraint of driver IC and a temperature of

10 - 30 °C under a constraint of measuring environment.

        As a result, it is confirmed that the

temperature dependence at a changed displayed under

20 application of a drive voltage of not more than 3.2 V

is not observed with respect to all the cells.

        In the cell having the cell thickness (a), red

display is effected at an applied voltage of 5 V but

it is visually identified that a change in display

25 color is caused to occur at an applied voltage of 5 V

due to the difference in environmental temperature.

        In the cell having the cell thickness (b),

blue display is effected at 5 V and red display is effected at 3.9 V. However, with respect to both of the display colors of blue and red, it is visually identified that a change in display color is caused to

5   occur due to the difference in environmental temperature.

In the cell having the cell thickness (c), blue display is effected at 4 V and red display is effected at 3.5 V. However, with respect to both of

10   the display colors of blue and red, it is visually identified that a change in display color is caused to occur due to the difference in environmental temperature although a degree of the change is somewhat reduced compared with the case of the cell

15   thickness (b).

In the cell having the cell thickness (d), blue display is effected at 3.6 V and used display is effected at 3.2 V. As a result, on a chromaticity diagram, different values for blue are obtained due to

20   the difference in environmental temperature during the blue display but the difference is not visually identified. Accordingly, the change in display color due to the difference in environmental temperature is not visually identified with respect to both of the

25   display colors of blue and red.

As described above, according to this comparative example, it is found that the temperature

dependence is of no problem for the cell thickness of

not less than 7 μm but it is difficult to obtain a

good characteristic as a color display apparatus with

respect to the cell thicknesses of less than 7 μm

5   since the temperature dependence is confirmed as the

change in display color when the cell has the cell

thickness of less than 7 μm.

(Example 1)

       Four types of cells are prepared in the same

10   manner as in Comparative Example 1 except that in

addition to the wide-band λ/4 plate, a unixial phase

difference plate having a retardation value of about

320 nm is disposed in lamination so that when a

polarization axis of the polarization plate is taken

15   as 0 degrees, an optical axis of the uniaxial phase

difference plate is located at a position forming an

angle of 45 degrees from the polarization axis in a

clockwise direction and an inclination direction of

liquid crystal molecules under voltage application

20   forms an angle of 45 degrees from the polarization

axis in a counterclockwise direction (i.e., the

direction of -45 degrees). As a result, the resultant

cells have such a normally blue constitution that a

blue display state is given at the time of no voltage

25   application and a change in hue is caused to occur at

the time of voltage application.

       When the four types of the cells are subjected

to measurement of a temperature dependence of

chromaticity, the following results are obtained.

In the cell having the cell thickness (a),

blue display is effected under no voltage application

5   and red display is effected at 2.8 V. These display

colors cause no change thereof, thus being stable. In

this cell, a white display state providing a maximum

reflectance is obtained at 3.75 V but more than half

of light for white display is reflected even under

10   application of a voltage of 5 V. This is because the

cell thickness is excessively small, so that the

retardation of liquid crystal layer fails to cancel

the retardation of phase difference plate even when

the retardation of liquid crystal layer is a maximum

15   value. When a 5 V application state is used as a black

state, a resultant contrast is not more than 2, thus

failing to provide a good display state.

In the cell having the cell thickness (a),

blue display is effected under no voltage application

20   and red display is effected at 2.65 V. These display

colors cause no change thereof, thus being stable. In

this cell, a white display state providing a maximum

reflectance is obtained at 3.3 V, and a black display

state is obtained at 5 V. This is because the

25   retardation of liquid crystal layer substantially

cancels the retardation of phase difference plate to

result in a total retardation of zero, i.e., the black

display state. As this time, the liquid crystal
molecules are aligned in a maximum inclination state,
so that the retardation of liquid crystal layer is
changed with the temperature change as described above
but only a luminance level of black is changed. As a
result, a change in hue is not caused to occur, so
that abnormal color is not caused to occur in the
display image. Further, a variation in black level is
not noticeable due to a low luminance, thus being
practically of no problem.

       In the cell having the cell thickness (a),
blue display is effected under no voltage application
and red display is effected at 2.55 V. These display
colors cause no change thereof, thus being stable. In
this cell, a white display state providing a maximum
reflectance is obtained at 3.1 V, and a black display
state is obtained at 4.25 V. The black level is
slightly fluctuated by changing the temperature but is
at an unobservable level through eye observation.

       In the cell having the cell thickness (a),
blue display is effected under no voltage application
and red display is effected at 2.5 V. These display
colors cause no change thereof, thus being stable. In
this cell, a white display state providing a maximum
reflectance is obtained at 2.95 V, and a black display
state is obtained at 4.25 V.

       According to this example, it is possible to

obtain such a characteristic that the temperature
dependence is practically of no problem in the cell
thickness of not less than 5 μm. IN other words,
compared with Comparative Example 1, it becomes

5   possible to set a thinner cell thickness.
(Example 2)

Four types of cells are prepared in the same
manner as in Comparative Example 1 except that the
unixial phase difference plate having a retardation

10   value of about 320 nm is changed to a three-layer
lamination film including two NH films (mfd. by NIPPON
OIL EXPLORATION Ltd.) having an in-plane retardation
of 110 nm and one NH film having an in-plane
retardation of 100 nm. When a polarization axis of the

15   polarization plate is taken as 0 degrees, an optical
axis of the NH films is located at a position forming
an angle of 45 degrees from the polarization axis in a
clockwise direction and an inclination direction of
liquid crystal molecules under voltage application

20   forms an angle of 45 degrees from the polarization
axis in a counterclockwise direction (i.e., the
direction of -45 degrees). Incidentally, NH films are
a phase difference plate in which polymeric liquid
crystal molecules are inclination-aligned, and are

25   used for the purpose of enlarging a viewing angle of
twisted nematic (TN) liquid crystal by utilizing a
biaxial anisotropy of refractive index.

    When the four types of the cells are subjected
to measurement of a temperature dependence of
chromaticity, similarly as in Example 1, it is
possible to obtain such a characteristic that the
temperature dependence is practically of no problem in
the cell thickness of not less than 5 µm. IN other
words, compared with Comparative Example 1, it becomes
possible to set a thinner cell thickness.

    When a viewing angle dependency is measured, a
better result than that by the constitution of Example
1 is obtained. Accordingly, it is confirmed that the
NH film is effective in enlarging the viewing angle
when it is used in not only TN-mode liquid crystal
display apparatus but also the liquid crystal display
apparatus according to the present invention. Further,
according to this example, an effectiveness of use of
the biaxial phase difference plate is confirmed.
(Example 3)

    A similar experiment to Example 2 was
performed. In this example, however, a WV film (mfd.
by Shumitomo Chemical Co., Ltd.) is disposed between
the polarization plate and the NH lamination film in
addition to the same constitution as Example 2. The WV
film is a phase difference plate in which a discotic
liquid crystal having a negative phase difference is
inclination aligned, and are used for the purpose of
enlarging the viewing angle of the TN liquid crystal.

When the WV film is disposed so that the
inclination alignment direction thereof is
perpendicular to that of the NH lamination film, such
a good result that the viewing angle characteristic is
well balanced is attained. On the other hand, when
these inclination alignment directions are aligned
with each other, the viewing angle characteristic is
somewhat poor in the direction of -45 degrees but is
improved in the direction of 45 degrees.

In other words, by lamination of the WV film,
it is possible to confirm the improvement effect of
the viewing angle characteristic with respect to not
only the TN liquid crystal but also the liquid crystal
mode in the present invention. Further, it becomes
possible to provide an optimum viewing angle
characteristic by appropriately adjusting the
direction of optical axis at the time of the
lamination.

(Example 4)

A similar experiment of Example 1 is performed.
In this example, however, an Sz film (mfd. by Sumitomo
Chemical Co., Ltd.) is used instead of the uniaxial
phase difference plate in Example 1. The Sz film is a
polymeric film, used for the purpose of improving a
viewing angle characteristic of an STN liquid crystal,
having an index ellipsoid satisfying: $nx > ny > nz$
wherein nx represents a refractive index of the phase

difference plate in a film optical axis direction, ny

represents a refractive index in a direction

perpendicular to the direction of nx in the plane of

the phase difference plate, and nz represents a

5   refractive index in a direction of a normal to the

phase difference plate.

The experiment is performed by using such an

Sz film that it has nx-ny value of 320 nm and

(nx-nz)/(nx-ny) value of 0.5.

10   Four types of liquid crystal cells having

different cell thicknesses as described above are

subjected to measurement of the temperature dependence

of chromaticity in the same manner as in Example 1. As

a result, similarly as in Example 1, it is possible to

15   obtain the temperature dependence of practically no

problem at the cell thickness of not less than 5 μm.

Accordingly, according to this example, it becomes

possible to set a thinner cell thickness than

Comparative Example 1.

20   When the viewing angle dependency is measured,

the result in this example is better than that in

Example 1. As a result, it is possible to confirm that

the Sz film can achieve the viewing angle enlarge

effect not only in the STN mode but also in the case

25   where the liquid crystal display apparatus of the

present invention is used. Further, it is also

possible to confirm the effectiveness of the biaxial

phase difference plate used in the liquid crystal

display apparatus of the present invention.

(Example 5)

5   An AM cell (display device) is prepared by

arranging the liquid crystal display devices having

the cell thickness (b) 5.0 μm described in Examples

1 - 4 in a matrix of 800x600 (SVGA) mode.

Each pixel is divided into two sub-pixels a1

provided with no color filter and a2 provided with a

10   green color filter as shown in Figure 2(a).

When a voltage is not applied to the liquid

crystal layer, blue display is effected at the

sub-pixel a1 provided with no color filter and a2

provided with a green color filter as shown in Figure

15   2(a).

When a voltage is not applied to the liquid

crystal layer, blue display is effected at the

sub-pixel a1 provided with no color filter and

substantially black display is effected at the

20   sub-pixel a2 provided with the color filter. When the

voltage is applied to the liquid crystal layer, the

display color at the sub-pixel a1 is changed from blue

to red at 2.6 V through violet and the display color

at the sub-pixel a2 remains substantially black as it

25   is. When the applied voltage is further increased, the

display color at the sub-pixel a1 is changed from

yellow to white at 3.3 V. Thereafter, a brightness of

white is gradually lowered while assuming achromatic

color as it is to provide gray, thus finally providing

black at about 5 V. At the sub-pixel a2, the color

(green) of the green color filter is visible at about

5   3.3 V and a brightness of green is gradually lowered,

while assuming green, with an increasing voltage, thus

finally providing also black at 5 V.

       As described above, at the sub-pixel a1, the

hue of the chromatic color is changed in a low voltage

10   range from 0 V to 3.3 V and the brightness of the

achromatic color is changed in high voltage range from

3.3 V to 5 V, so that the voltage modulation is

effected over both of these low and high voltage

ranges, it is possible to effect display of both the

15   chromatic colors of blue, red and colors having their

intermediary hues and the achromatic colors of

halftones of the achromatic colors from white to black.

On the other hand, at the sub-pixel a2 provided with

the green color filter, it is possible to effect

20   continuous gradation display of green in the voltage

range from 3.3 V to 5 V.

       According to this example, it is possible to

display all the three primary colors (RGB), so that a

color display can be effected by driving the AM cell

25   in the low and high voltage ranges with a threshold

voltage for displaying white (3.3 V in this example)

at the sub-pixel a1 and in the high voltage range at

the sub-pixel a2 and by using the resultant colors in combination. It is also possible to partially display halftones.

Further, the resultant hue can be expected

5   that it is not changed with temperature.

(Example 6)

An AM cell is prepared in the same manner as in Example 5 except that the sub-pixel provided with no color filter is further divided into two portions,

10   which are provided with a magenta color filter. More specifically, as shown in Figure 2(b), each pixel b is divided into three sub-pixels including a sub-pixel b2 provided with a green color filter, and sub-pixels b1 and b3 which are provided with the magenta color

15   filter and have an areal ratio of 1:2. By driving the AM cell at these sub-pixels independently, it is possible to effect halftone display of an arbitrary chromatic color from blue to red at four gradation levels. Further, by the color filters, color purities

20   of the display colors of blue and red are increased.

According to this example, similarly as in Example 5, it is possible to confirm that all the RGC primary colors are displayable and that a color reproducibility is improved compared with Example 5.

25   Further, it is also similarly possible to except that the hue is not changed with temperature.

(Example 7)

An AM cell is prepared by using the liquid crystal display devices having the cell thickness (b) 5.0 μm described in Examples 1 - 4 with pixels each divided into six sub-pixels as shown in Figure 3. More specifically, each pixel is divided into six sub-pixels R, G B, M1, M2 and M3, provided with color filters of red, green, blue, magenta, magenta, and magenta, respectively. The sub-pixel G has an areal which is 1/3 of the area of each pixel. In the remaining area (2/3 of the area of each pixel), the five sub-pixels R, B, M1, M2 and M3 are disposed at an areal ratio of 1:1:1:2:4.

As a result, it is possible to confirm that all the RGB primary colors are displayable and that the color reproducibility is increased compared with Example 5. Further, it is also possible to confirm that the hue is not changed with temperature. In addition, it is possible to confirm that complete full-color display can be effected.

(Example 8)

Four types of AM cells are prepared in the same manner as in Comparative Example 1 except that the wide-band λ/4 plate is changed to a unixial phase difference plate having a retardation value of about 400 nm so that when a polarization axis of the polarization plate is taken as 0 degrees, an optical axis of the unixial phase difference plate is located

at a position forming an angle of 45 degrees from the polarization axis in a clockwise direction and an inclination direction of liquid crystal molecules under voltage application forms an angle of 45 degrees

5   from the polarization axis in a counterclockwise direction (i.e., the direction of -45 degrees). As a result, the resultant cells have such a normally blue constitution that a green display state is given at the time of no voltage application although a color

10   purity is not so high and that a change in hue is caused to occur at the time of voltage application.

When the four types of the cells are subjected to measurement of a temperature dependence of chromaticity, the following results are obtained.

15   In the cell having the cell thickness (a), green display is effected under no voltage application, blue display is effected at 2.85 V, and used display is effected at 3.5 V. With respect to these display colors, green and blue are not changed due to the

20   change in environmental temperature but red is changed due to the change in environmental temperature. Further, at 5 V, a white display state providing a maximum reflectance is obtained but a black display state cannot be obtained.

25   In the cell having the cell thickness (b), green display is effected under no voltage application, blue display is effected at 2.7 V, and used display is

effected at 3.15 V. With respect to these display
colors, all the display colors (three primary colors)
are not changed due to the change in environmental
temperature, thus being stable against temperature.

5   Further, at 4.2 V, a white display state providing a
maximum reflectance is obtained but a reflectance is
approximately 3/4 of a reflectance at the time of
white display even when a voltage of 5 V is applied,
thus failing to provide a white/black contrast.

10   In the cell having the cell thickness (c),
green display is effected under no voltage application,
blue display is effected at 2.6 V, and used display is
effected at 2.95 V. With respect to these display
colors, all the display colors (three primary colors)

15   are not changed due to the change in environmental
temperature, thus being stable against temperature.
Further, at 3.65 V, a white display state providing a
maximum reflectance is obtained and a 5 V, a black
display state is obtained. However, a resultant

20   contrast is low, i.e., about 6, thus failing to obtain
a complete black level. Incidentally, the black level
is somewhat changed by changing the temperature but is
a level of practically no serious problem. As a result,
it is possible to effect stable display of the three

25   primary colors and stable white/black display with
respect to the temperature.

            In the cell having the cell thickness (d),

green display is effected under no voltage application, blue display is effected at 2.55 V, and used display is effected at 2.8 V. With respect to these display colors, all the display colors (three primary colors)

5 are not changed due to the change in environmental temperature, thus being stable against temperature. Further, at 3.35 V, a white display state providing a maximum reflectance is obtained and a 4.55 V, a black display state is obtained. Further, a resultant

10 contrast is about 30, thus being a practically sufficient level. Incidentally, the black level is slightly changed by changing the temperature but is an unrecognizable level through eye observation.

According to this example, with respect to the

15 cell thickness of not less than 7.0 μm, the three primary colors are displayable and such a display characteristic that a contrast ratio so high. Further, it becomes possible to provide the temperature dependence of practically no problem.

20 (Example 9)

In this example, with respect to such a constitution as in Example 8 that green display is effected under no voltage application, the biaxial phase difference plates (films) similar to those used

25 in Examples 2 to 4 are evaluated. As a result, also with respect to the normally green constitution, the viewing angle improvement effect is attained by the

biaxial phase difference plates, so that it is possible to confirm the effectiveness of the biaxial phase difference plates.

(Example 10)

An AM cell having a cell thickness of 7.0 μm is prepared in the same manner as in Example 8 except that the pixel constitution is changed to that shown in Figure 4. More specifically, one pixel is divided into six sub-pixels R, G, B, C1, C2 and C3 provided with color filters of red, green, blue, cyan, cyan and cyan, respectively. The sub-pixel R provided with the red color filter has an area which is 1/3 of the area of each pixel. IN the remaining area (2/3 of the area of each pixel), the five sub-pixels G, B, C1, C2 and C3 have an areal ratio of 1:1:1:2:4.

As a result, it is possible to confirm that all the RGB primary colors are displayable and that the color reproducibility is increased compared with Example 8. Further, it is also possible to confirm that the hue is not changed with temperature. In addition, it is possible to confirm that complete full-color display can be effected.

(Example 11)

In this example, an irregularity in display color when a uniformity in cell thickness is not obtained in a cell preparation process is evaluated with respect to the cells prepared in Examples 1 to 10.

As a result, it is possible to confirm that degrees of
the display color irregularity with respect to all the
cells in Examples 1 to 10 are smaller than that in the
case of Comparative Example 1.

5

[INDUSTRIAL APPLICABILITY]

As described hereinabove, according to the
present invention, it is possible to realize a color
liquid crystal display apparatus which utilizes such
10   an ECB effect-based coloring phenomenon that the
temperature dependence of hue is not visually
identified.

In the above description, the reflection-type
liquid crystal display apparatus is principally
15   described. However, the present invention is not
limited thereto but is also applicable to a
transmission-type liquid crystal display apparatus and
a transflective-type liquid crystal display apparatus.
Further, in the present invention, as the drive
20   substrate, the TFT substrate is used but may be
replaced with a substrate provided with MIM
(metal-insulator-metal). Further, it is also possible
to employ a drive method in which the cell has a
simple matrix structure.

25

CLAIMS

1. A liquid crystal display apparatus, comprising:

at least one polarization plate,

a phase difference plate,

a pair of oppositely disposed substrates at least one of which is a transparent substrate,

a liquid crystal disposed between said pair of substrates, and

means for applying a voltage to said liquid crystal so that a retardation of said liquid crystal is modulated depending on the voltage applied to said liquid crystal,

wherein said liquid crystal is placed in a first alignment state which is determined by said pair of substrates when the voltage is not applied thereto,

wherein said phase difference plate has a retardation so that light passing through said liquid crystal, said phase difference plate, and said polarization plate assumes chromatic color when the voltage is not applied to said liquid crystal, and

wherein said liquid crystal is placed in a second alignment state in which said liquid crystal is aligned obliquely compared with the first alignment state so that the retardation of said liquid crystal cancels the retardation of said phase difference plate

when the voltage is applied to said liquid crystal.

2.   An apparatus according to Claim 1, wherein,
when a voltage having a value which is not more than a
predetermined value is applied to said liquid crystal,
the retardation of said liquid crystal is modulated in
a hue change range in which the light passing through
said liquid crystal, said phase difference plate, and
said polarization plate assumes chromatic color and a
hue of the chromatic color is changed depending on the
applied voltage and, when a voltage having a value
which is not less than the predetermined value is
applied to said liquid crystal, the retardation of
said liquid crystal is modulated in a light brightness
change range in which a brightness of the light
passing through said liquid crystal, said phase
difference plate, and said polarization plate is
changed depending on the applied voltage.

3.   An apparatus according to Claim 2, wherein the
voltage having the predetermined value is a voltage
for effecting white display.

4.   An apparatus according to Claim 2, wherein
said apparatus effects black display when a maximum
voltage which is not less than the voltage having a
predetermined value is applied.

5.   An apparatus according to Claim 2, wherein
said apparatus has a first area in which the
retardation of said liquid crystal is modulated over
5   the hue change range wherein the hue of the chromatic
color is changed depending on the applied voltage
having the value which is not more than the
predetermined value and the brightness change range
wherein the brightness is changed depending on the
10 applied voltage having the value which is not less
than the predetermined value, and a second area in
which a color filter is provided and the retardation
of said liquid crystal is modulated in the hue change
range wherein the brightness is changed depending on
15 the applied voltage having the value which is not less
than the predetermined value.

6.   An apparatus according to Claim 1, wherein the
unit pixel is constituted by a plurality of sub-pixels
20 including a first sub-pixel at which the retardation
of said liquid crystal is modulated over the hue
change range wherein the light passing through said
liquid crystal, said phase difference plate, and said
polarization plate assumes the chromatic color and the
25 hue of the chromatic color is changed and a brightness
change range wherein the light assumes achromatic
color and a brightness of the achromatic color is

changed, and a second sub-pixel at which a color filter is provided and the retardation of said liquid crystal is changed in the brightness change range wherein the brightness of the light passing through

5   said liquid crystal, said phase difference plate, and said polarization plate is changed.

7.   An apparatus according to Claim 6, wherein the chromatic color at the first sub-pixel when the

10   voltage is not applied to said liquid crystal is blue or bluish green.

8.   An apparatus according to Claim 7, wherein the color filter provided at the second sub-pixel is a

15   green color filter.

9.   An apparatus according to Claim 8, wherein at the first sub-pixel, a color filter of color complementary to green.

20

10.   An apparatus according to Claim 6, wherein the chromatic color at the first sub-pixel when the voltage is not applied to said liquid crystal is green.

25   11.   An apparatus according to Claim 10, wherein the color filter provided at the second sub-pixel is a red color filter.

12. An apparatus according to Claim 11, wherein at the first sub-pixel, a color filter of color complementary to red.

13. An apparatus according to Claim 1, wherein said liquid crystal has a voltage range in which a change ratio of the retardation to a temperature is substantially zero.

14. An apparatus according to Claim 1, wherein said phase difference plate has a biaxial refractive index.

15. An apparatus according to Claim 14, wherein said phase difference plate has refractive indices nx, ny and nz satisfying:

$$nx > nz > ny,$$

wherein nx represents a refractive index of said phase difference plate in an optical axis direction, ny represents a refractive index in a direction perpendicular to the optical axis in a plane of said phase difference plate, and nz represents a refractive index in a thickness direction of said phase difference plate.
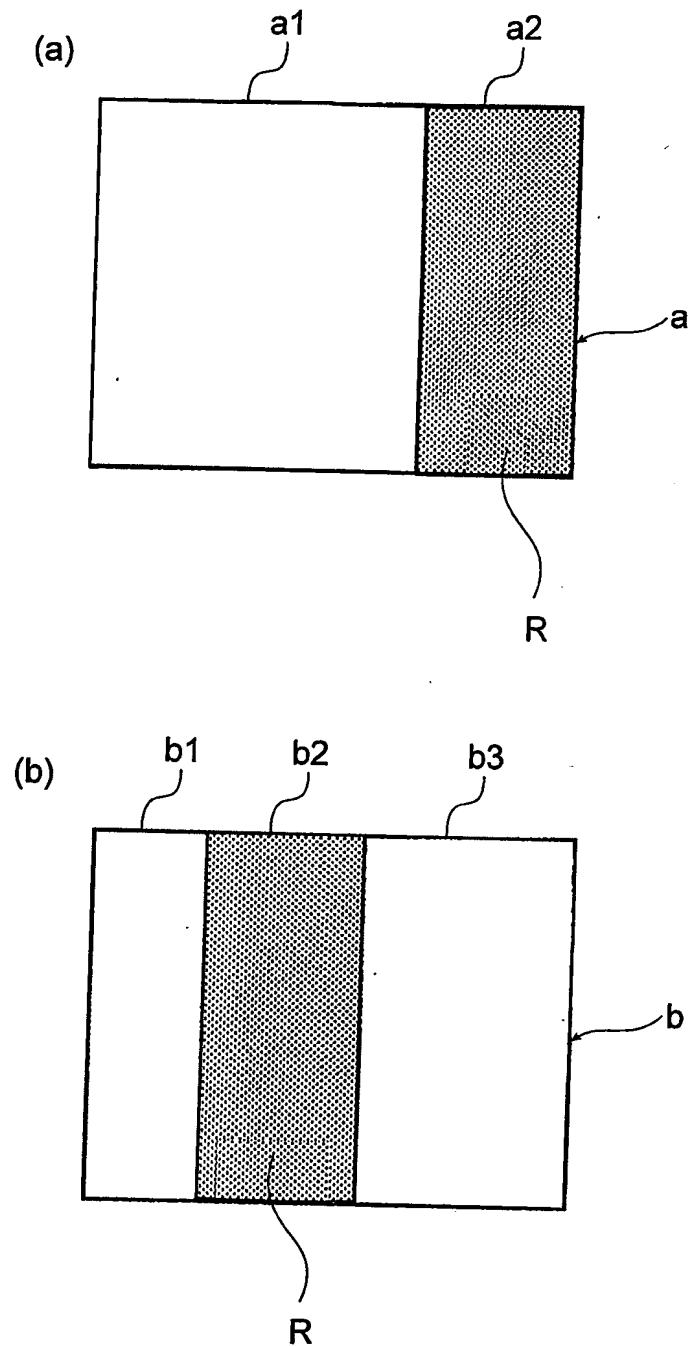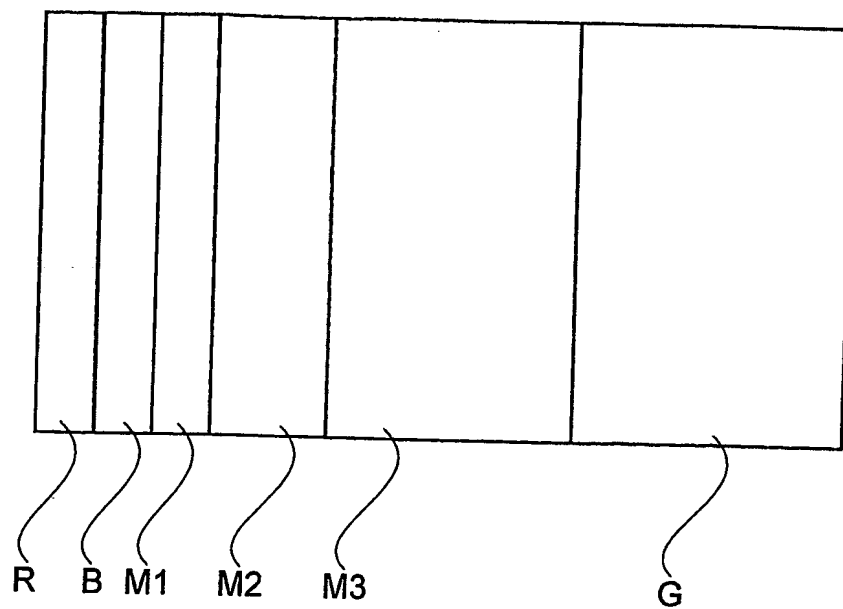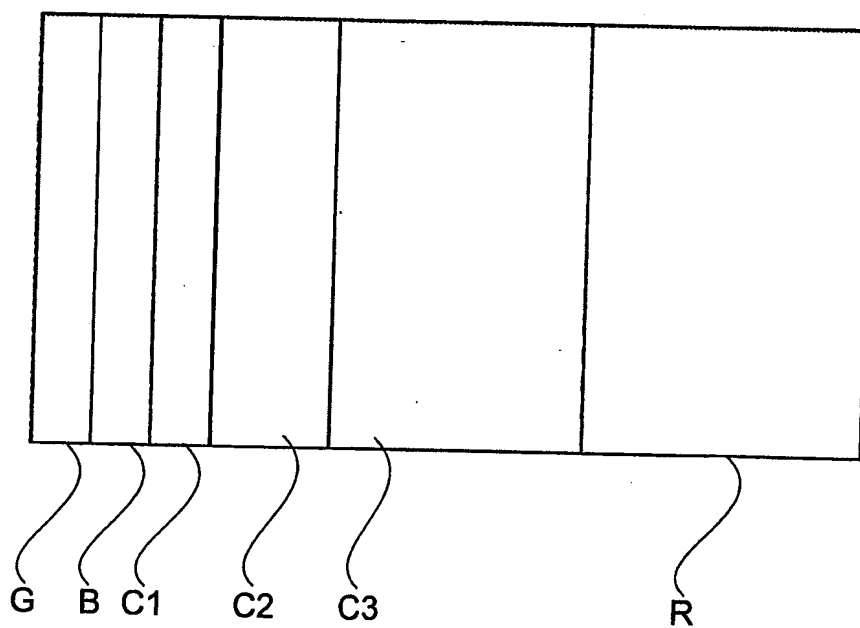
FIG.1

(a)

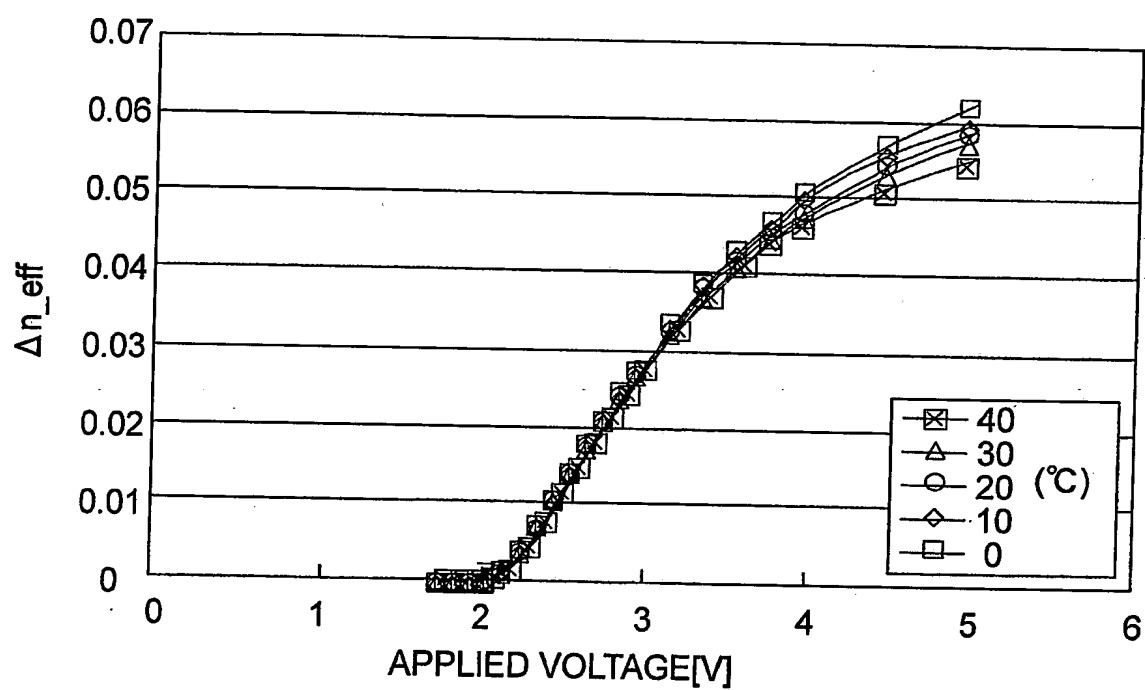a1   a2

a

R

(b)

b1   b2   b3

b

R
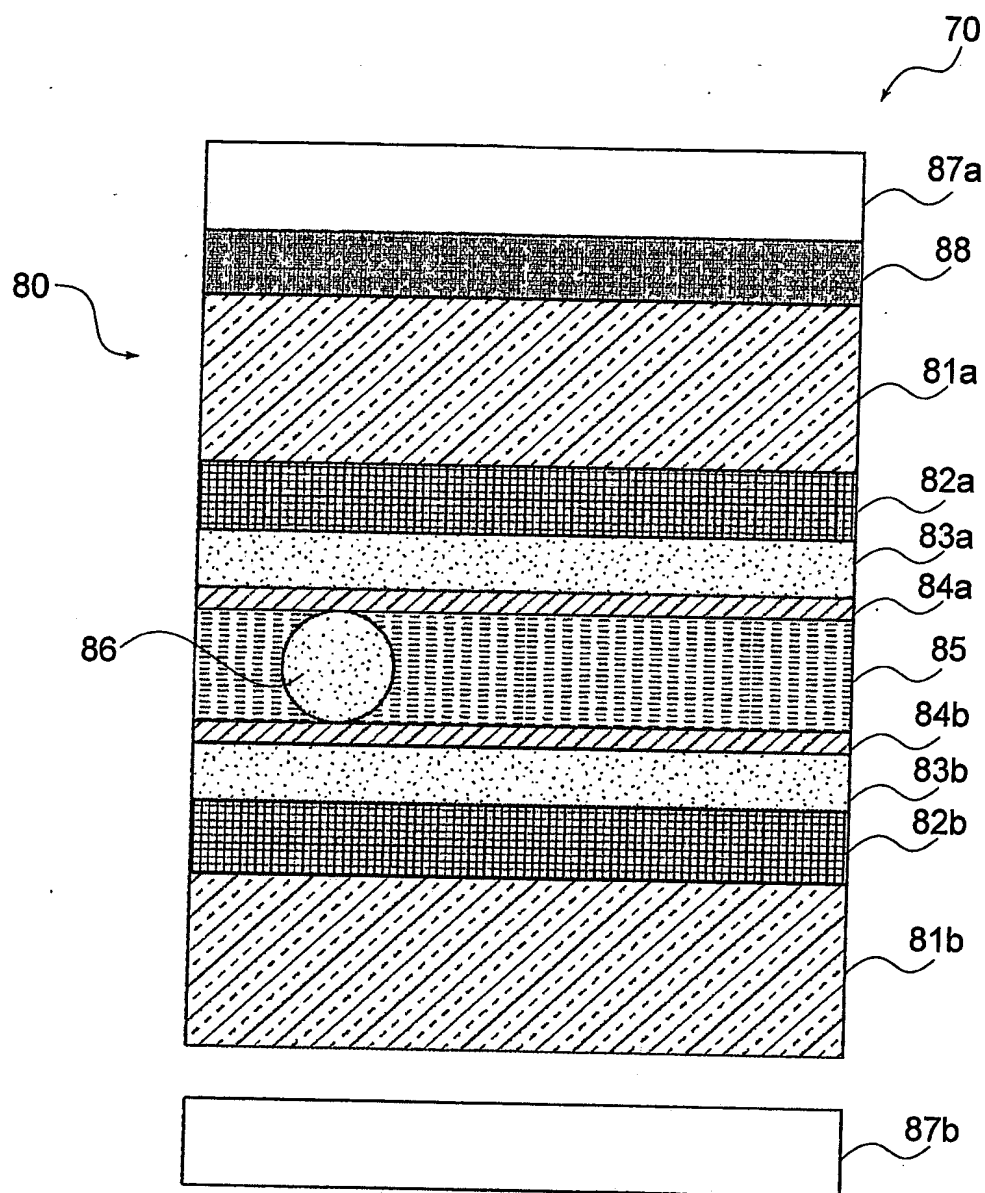
FIG.2

FIG.3

FIG.4

FIG.5
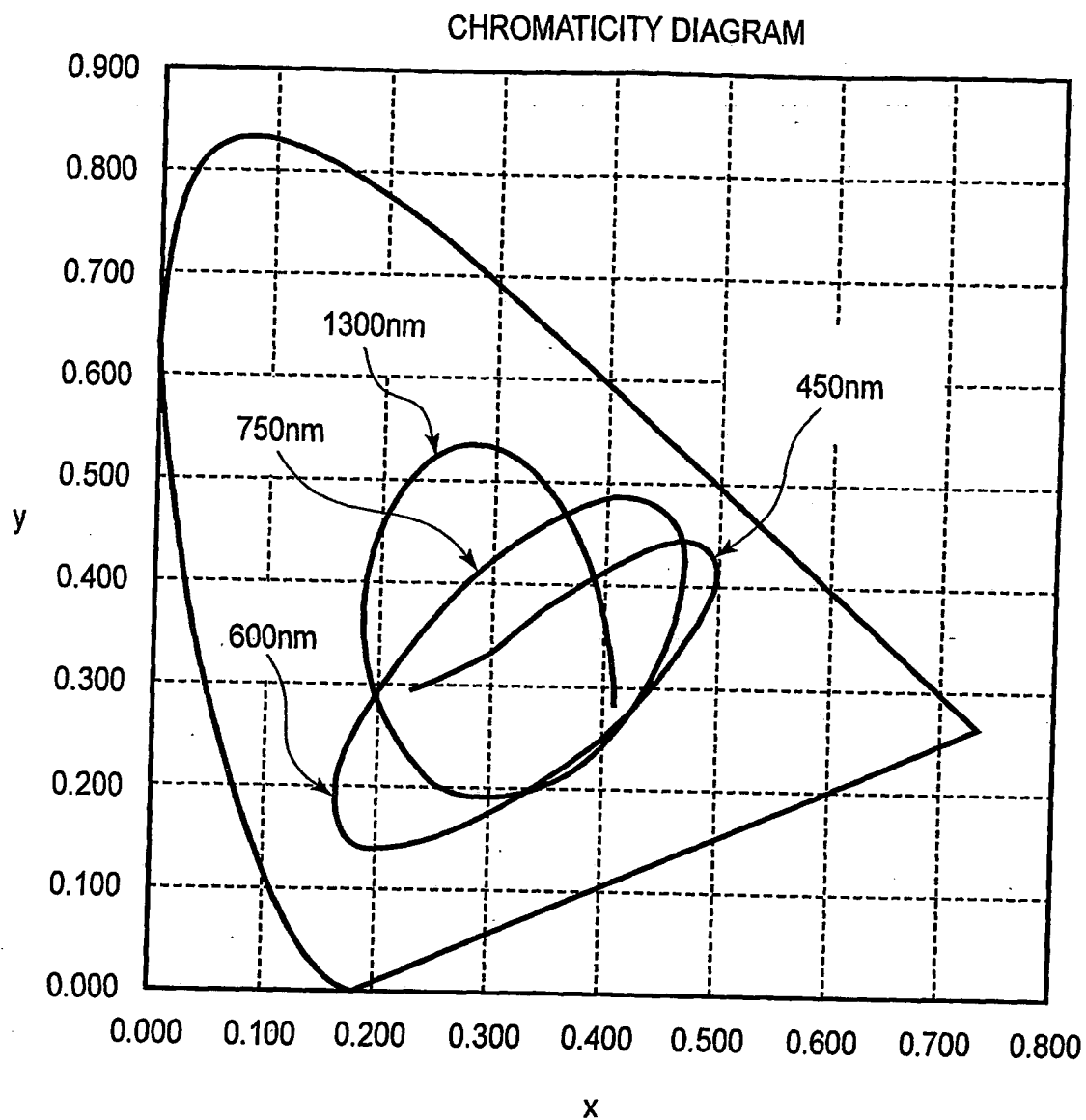
FIG.6
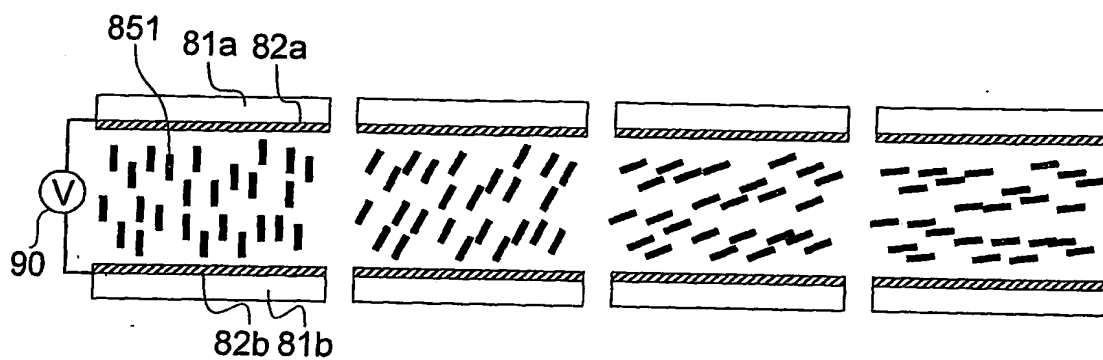
FIG.7
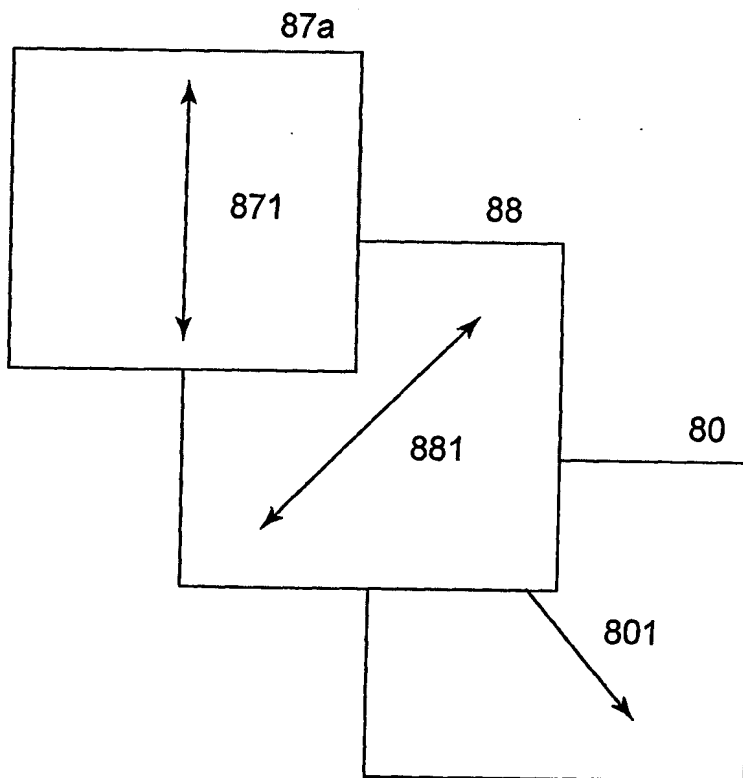
FIG.8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   G02F1/13363   G02F1/139   G02F1/1335

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, IBM-TDB, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	ASSOULINE G ET AL: "liquid-crystal display with electrically controlled birefringence" ELECTRONICS LETTERS UK, vol. 8, no. 2, 27 January 1972 (1972-01-27), pages 45-46, XP002335593 ISSN: 0013-5194 page 700, left-hand column; figure 2	13

[X] Further documents are listed in the continuation of box C.   [X] Patent family members are listed in annex.

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Date of the actual completion of the international search

11 July 2005

Date of mailing of the international search report

11/08/2005

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Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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